Nutrients

Nitrogen Loads to Galveston Bay

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Nitrogen is a critical macronutrient in assessing estuarine eutrophication potential. Population growth in the Galveston Bay watershed has led to increases in the amount of nitrogen introduced in point source discharges. In addition, increased urbanization and more intensive agricultural activity would be expected to result in increases in nitrogen. On the other hand, reservoir development in the watershed traps particulate material, resulting in the removal of nitrogen that would otherwise have entered the bay. Reservoir development and water supply systems have also resulted in shifts in the points at which freshwater and nitrogen are introduced into the bay, and some nitrogen introduced to the bay is removed in the course of routine maintenance dredging.

This paper presents an analysis of the variation in the major nitrogen loads to the bay system over the last 20 years developed from a range of data sources. These include the extensive data of the City of Houston's (CoH) wastewater treatment system, studies of the historical and projected freshwater needs of the Houston metropolitan area, and available routine monitoring data from the major tributaries to the system. The analysis also includes estimates of nitrogen loads in earlier periods.

Using U.S. Geological Survey (USGS) data for all of the major gaging stations in the bay watershed, it was determined that a total nitrogen (TN) concentration (sum of TKN, NO_2 and NO_3-N) of approximately 1.2 mg/l was representative of the watersheds with the least development. Recognizing that all streams in the bay watershed are influenced by anthropogenic sources to a degree, a value of one mg/l was taken as representing background inputs in the absence of man's presence. It is recognized that this background level might be somewhat lower if it were possible to completely eliminate airborne inputs from agricultural and combustion sources.

Annual average inflows to the bay system are on the order of 11,300 cfs, with substantial variation year to year. Roughly 75% on average of this flow is contributed by the Trinity River. Using the background TN level of one mg/l and the average flow, the annual TN load to Galveston Bay is 68,000 lbs/day (11,200 MT/yr). This would be the load that could be expected pre-1900.

Over the last twenty years, there has been developed reasonably good data on the TN loads from permitted point sources. The CoH in particular operates an extensive and highly automated laboratory complex that serves both a regulatory and operations function. Data compiled by the City go through extensive quality checks and are stored on a central computer data bank. Data were retrieved for the years 1971-90 and annual average flows and TN loads computed (Fig. 1).

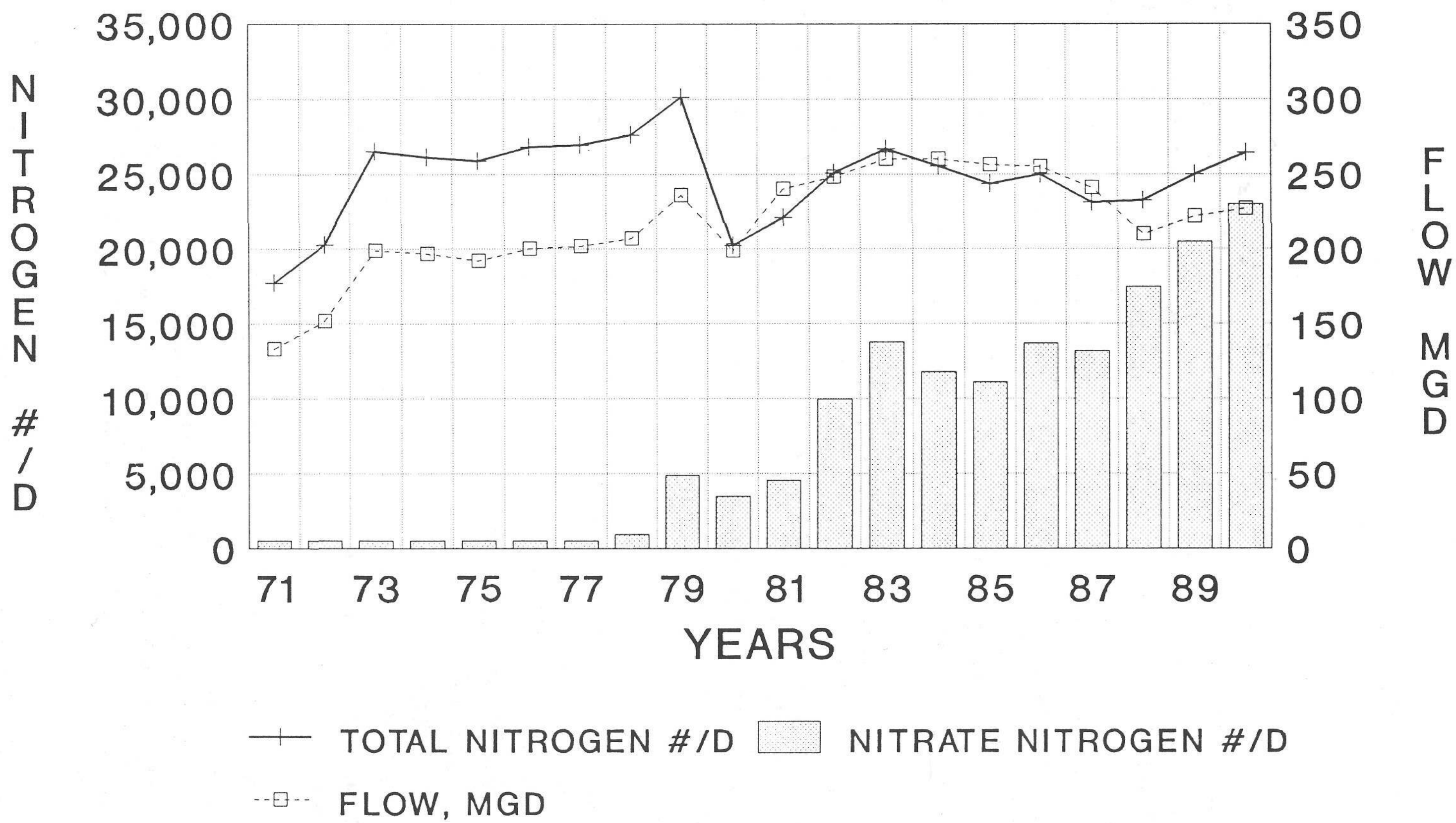

Figure 1. City of Houston treated wastewater flow and nitrogen load, 1971-1990.

During this period, the annual average TN load from the CoH treatment facilities, which represent about 69% of the flow of the entire domestic wastewater for the bay, was on the order of 25,000 lbs/day. Extrapolating to the entire bay using CoH data yielded a total during the 1980s of about 35,000 lb/day (5,700 MT/yr). An interesting aspect of these data is that over the period 1978 to 1990, the distribution of this TN load has changed substantially. At the beginning of the period, nitrate-N represented three % of the TN while at the end this percentage had grown to over 86%.

Industrial flows were taken from Texas Water Commission (TWC) publications and TN values taken from recent intensive survey data. These data are not nearly as complete as the CoH source for domestic wastewater, but are the best uniform information available. It was found that for industries along the Houston Ship Channel (HSC), the average flow weighted TN concentration was 8.8 mg/l, considerably lower than for domestic wastewater as would be expected. The industries along the HSC were found to represent roughly 70% of the total bay industrial flow, and the TN load during the 1980s was approximately 15,000 lbs/day (2,500 MT/yr).

The next step was to estimate loads at decade intervals back to 1890, using the population of the City as a scaling factor for domestic and industrial loads prior to 1970. No attempt was made to adjust average concentrations for a lower level or absence of waste treatment during these years. By scaling in this way, a fairly dramatic increase in the average annual TN load, corresponding to the growth in the area, can be seen. The greatest growth occurred during the period 1940-1970. Substantial growth also occurred during the 1970s, but improvements in wastewater treatment offset this growth.

Another change that has occurred over time is the increase in basin transfers and points where water enters the bay. Currently there is about 75 MGD of Brazos River water added to the western portion of the bay along with roughly 100 MGD of groundwater. Also, on the order of 300 MGD of Trinity River water is diverted to the western side of the bay. All of these transfers enter as domestic and industrial return flows. Finally, removal of TN occurs in navigation channel dredging. About 500 MT/yr of TN are removed by dredging the HSC above Morgan's Point.

However, the biggest change in the bay system occurred when Lake Livingston began filling in 1972. Prior to that time, growth in the Dallas/Ft. Worth metropolitan area was producing a substantial increase in the TN concentration of the Trinity River. During the period 1972-88, the Trinity River at Crockett (the last gage before Lake Livingston) had an average TN concentration of 4.14 mg/l, roughly four times as high as undeveloped background conditions. The lake has a substantial effect on these TN levels. The TN data for the same period at Romayor (immediately below Livingston) are 1.07 mg/l, roughly a 75% reduction. Figure 2 shows these data averaged for two periods, 1970-88 and 1983-88. The reduction across Lake Livingston in TN, particularly the inorganic forms, is quite strong. A similar process occurred with Lake Houston although the reductions appear to be only on the order of 50%, reflecting a much smaller lake.

Assuming that the higher TN levels found above Lake Livingston are associated

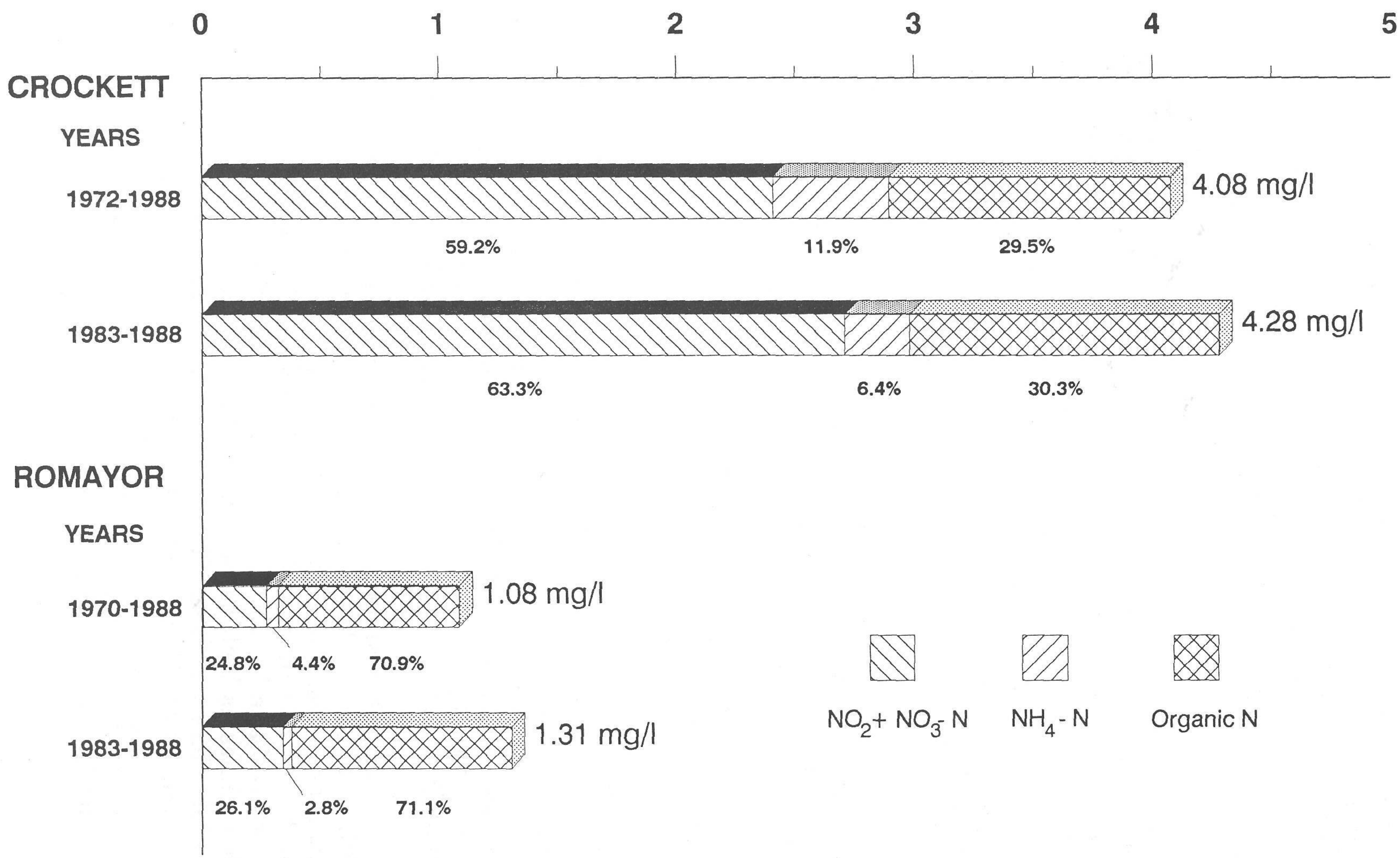

Figure 2. Trinity River nitrogen concentrations.

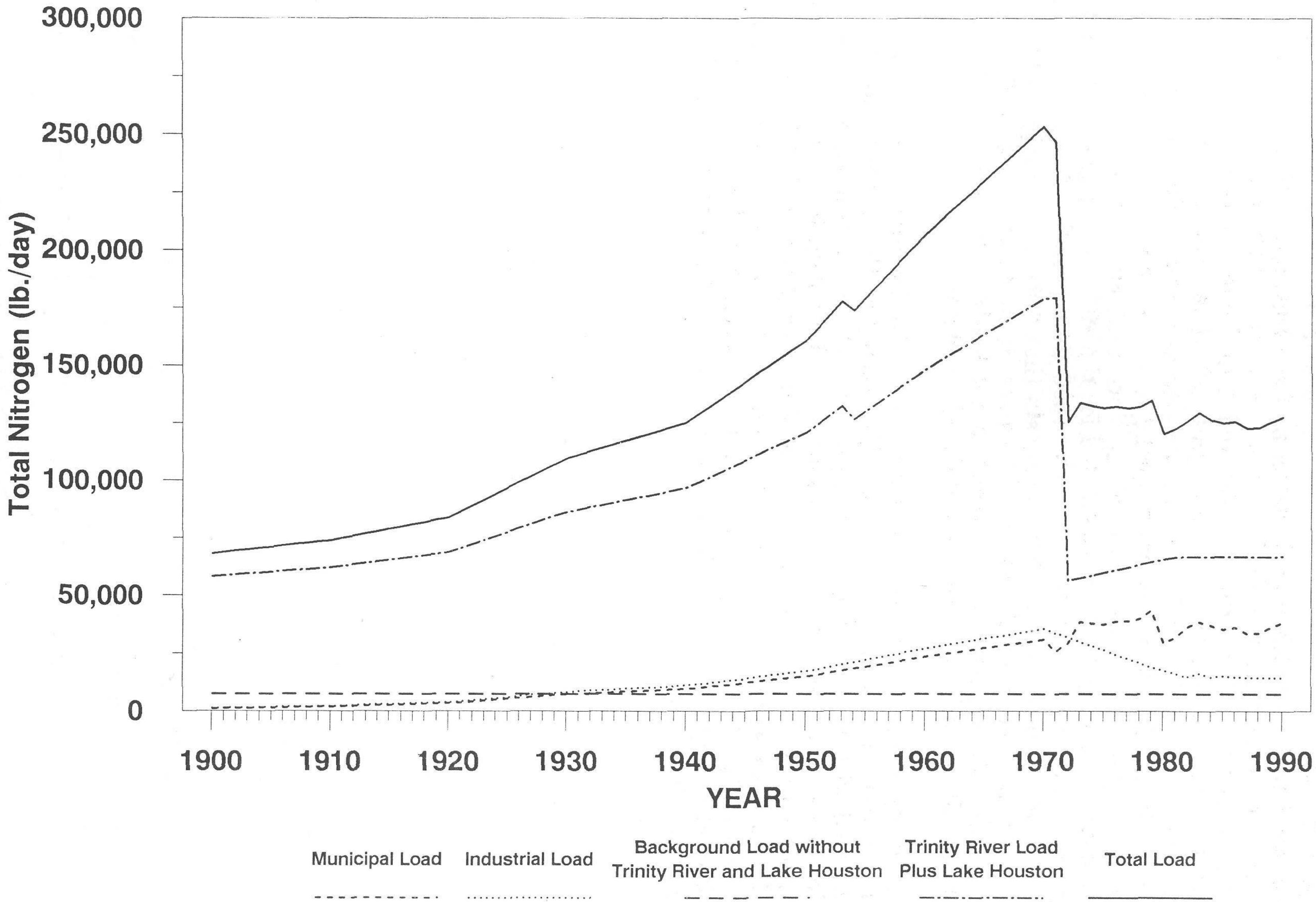

Figure 3. Galveston Bay nitrogen loads.

with human activity, the increase above background was scaled to population growth. A 75% reduction in this load was imposed in 1972, along with a 50% reduction in the San Jacinto River load, reflecting Lake Houston in 1955. Figure 3 illustrates the overall pattern found. The three lower lines in the figure represent the background load without the Trinity and San Jacinto rivers (the great majority of the watershed), the domestic and industrial loads. These three components, along with the load from the Trinity and San Jacinto rivers, are combined into the total load, shown with a solid line. The data suggest that the TN load to the bay probably peaked in 1971. Since that time, the load has held relatively steady at roughly the level calculated for the 1940 period. This TN load is roughly twice the amount calculated for the 1900 time period, substantially in the absence of major development. This suggests that offsetting processes have limited any major change in TN loads. However, it must be recognized that under dry periods the concentration of point source loads on the western side of the bay could still result in localized man-induced problems.

The methodology employed in this analysis is relatively simple and several potentially important factors are ignored. For example, the timing and river flows associated with the TN loads have a great effect on the residence time for nitrogen in the bay and the amount that would be used by plant life. Dealing with average flows obviously ignores wide year-to-year variations in TN loads and resulting bay concentrations. However, the analysis is sufficient to suggest that with the relatively small changes seen in the overall bay loadings, future consideration of nitrogen concentrations should focus on the western side of the bay under lower flow conditions.

The Cycling of Nutrients in Galveston Bay: Factors Regulating their Concentrations

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The fate of many trace elements is related to that of nutrients, either by coincidence of inputs, or similar removal or regeneration mechanisms. Therefore, any geochemical investigation of trace elements has to start with that of nutrients. However, no systematic study of nutrient cycling in Galveston Bay has been carried out in the last decade. Excessive nutrient inputs to coastal areas can be the cause for hypoxic events, nuisance algae blooms and, in areas with low mixing energy, for fish kills. Galveston Bay is receiving nutrient inputs mainly from rivers, but also from drainage from urban and agricultural areas, domestic sewage and from the atmosphere. Important questions concerning nutrient and light limitation of algae growth, and concerning the importance of benthic nutrient regeneration in the bay, have so far not been addressed. Our approach to investigate factors controlling concentrations of nutrients in Galveston Bay has been the following:

1. The data base of the Texas Water Commission (TWC, 1980-1989) was transferred into Lotus-123 (for IBM-PC) and Excel (for Macintosh) formats.

2. Correlations and time-series analyses were carried out on the monthly measurements of concentrations of nutrient elements, chlorophyll *a*, temperature, and salinity at the mid-bay station Smith Pt./Eagle Pt. in Galveston Bay, in order to establish seasonality and regulating factors for nutrient species in the bay.

3. Results from the above correlation and time series analyses were compared with those from other stations in Trinity Bay, Buffalo Bayou, and East and West Bay, in order to establish the general applicability of the conclusions.

4. Nutrient measurements were carried out in 1989 along salinity transects in the bay to test the seasonality of nutrient concentrations, as well as to establish sources and sinks.

From time series analysis of chemical data sets from one of the stations sampled monthly by the TWC in the middle of Galveston Bay (half-way between Smith and Eagle Pt.), we made the following observations: The annual pattern of phosphate, total inorganic nitrogen and chlorophyll *a* in the last ten years exhibits strong seasonal cycles, which appear to be related to temperature. Optimum ($P < 0.001$) cross-correlations with temperature (T) were observed for phosphate data, when the phosphate data were shifted by one month (i.e., PO_4 maximum one month after T maximum, i.e., in September). This could indicate: 1) Higher rates of phosphate regeneration from the sediments in the fall due to phosphate release associated with the formation of iron sulfides in the sediments; and 2) Control by maxima of phytoplankton biomass during spring causing minima of phosphate concentrations during that time. The chlorophyll *a* data from the last three years cross-correlated well with temperature when the chlorophyll *a* data were shifted forward by four months, indicating a spring bloom occurring in March-April. Total inorganic nitrogen significantly ($P < 0.001$) and inversely correlated with salinity, with a correlation optimum at a phase shift of three months after the salinity maximum. Such a pattern could be caused by four different mechanisms: 1) Nitrogen inputs from storm sewer overflows during high rainfall events in the drainage basin of the Trinity River, delayed by the typical water residence time in the reservoir lakes of the Trinity River; 2) Control by denitrification losses in reservoir lakes along the Trinity River such as Lake Livingston. Dentrification losses would be at their lowest during times of shortest water residence times in these lakes associated with highest freshwater flows; 3) Maxima of denitrification losses in Galveston Bay during times when the salinity of bay waters is at its highest. Nitrogen losses by denitrification in the bay are supported by frequent observations of close to zero concentration of nitrate during the summer months; and 4) In-situ control by nitrification processes in the bay during times of lower salinity. More extensive studies are required to test these hypotheses.

Nutrient concentrations from water samples taken during two Trinity River to Gulf of Mexico transects in August and October, 1989 showed that phosphate concentrations were considerably higher during the warm August month than during the colder October, confirming long-term trends for concentration maxima during the late summer months. Both nitrate and phosphate showed concentration maxima in the intermediate salinity range, indicating an extra source, possibly nutrients regenerated from sediments.

In the future, we will attempt to investigate the importance of fluxes from the atmosphere and from the sediments to the cycling of nutrient and trace elements in the bay.